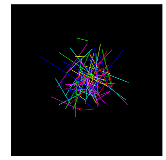
- Previous Lecture:
  - File I/O, use of cell array
- Today's Lecture:
  - Structures
  - Structure array (i.e., an array of structures)
  - A structure with array fields
- Announcements:
  - Project 5 due Thurs 11/6 at 11pm. Reduced late penalty of 5% applies to submission made up to 11/7 at 11pm
  - Prelim 2 on Thurs 11/13 at 7:30pm. Email Randy Hess (rbh27) now if you have an exam conflict (include the course and instructor info of the conflicting exam)

Data are often related

- A point in the plane has an x coordinate and a y coordinate.
- If a program manipulates lots of points, there will be lots of x's and y's.
- Anticipate clutter. Is there a way to "package" the two coordinate values?



Packaging affects thinking

Our Reasoning Level:

P and Q are points. Compute the midpoint M of the connecting line segment.

Behind the scenes we do this:

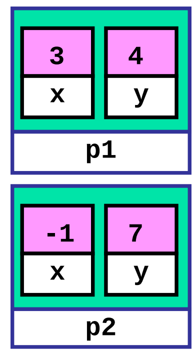
$M_x = (P_x + Q_x)/2$
$M_y = (P_y + Q_y)/2$

We've seen this before: functions are used to "package" calculations.

This packaging (a type of abstraction) elevates the level of our reasoning and is critical for problem solving.

Example: a Point structure

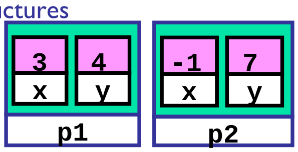
```
% p1 is a Point
p1.x= 3;
p1.y= 4;

% p2 is another Point
p2.x= -1;
p2.y= 7;
```



A Point has two properties—fields—x and y

Working with Point structures

```
p1.x=3;  p1.y=4;
p2.x=-1; p2.y=7;
```

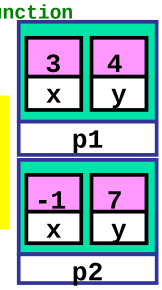



```
% Distance between points p1 and p2
D= sqrt((p1.x-p2.x)^2 + (p1.y-p2.y)^2);
```

Note that **p1.x, p1.y, p2.x, p2.y** participate in the calculation as variables—because they are.

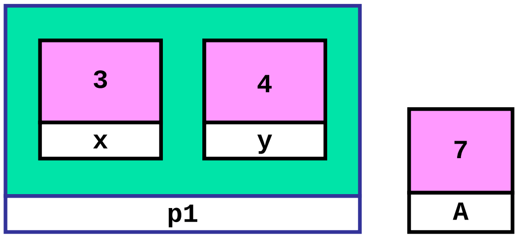
Different ways to create a structure

```
% Create a struct by assigning field values
p1.x= 3;
p1.y= 4;
% Create a struct with built-in function
p2 = struct('x',-1, 'y',7);
```



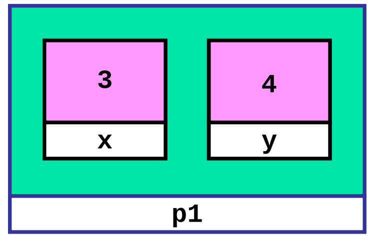
p2 is a structure.
The structure has two fields.
Their names are **x** and **y**.
They are assigned the values -1 and 7.

Accessing the fields in a structure



`A = p1.x + p1.y;` *Assigns the value 7 to A*

Assigning to a field in a structure



`p1.x = p1.y^2;` *Assigns the value 16 to p1.x*

A structure can have fields of different types

```
A = struct('sname', 'New York',…
           'capital', 'Albany',…
           'pop', 15.5)
```

- Can have combinations of string fields and numeric fields
- Arguments are given in pairs: a field name, followed by the value

Legal/Illegal maneuvers

```
Q = struct('x',5,'y',6)

R = Q          % Legal. R is a copy of Q

S = (Q+R)/2    % Illegal. Must access the
               % fields to do calculations

P = struct('x',3,'y') % Illegal. Args must be
                      % in pairs (field name
                      % followed by field
                      % value)

P = struct('x',3,'y',[]) % Legal. Use [] as
P.y = 4                  % place holder
```


Structures in functions

```
function d = dist(P,Q)
% P and Q are points (structure).
% d is the distance between them.

d = sqrt((P.x-Q.x)^2 + ...
         (P.y-Q.y)^2);
```


Example "Make" Function

Good style: use a "make" function to highlight a structure's definition

```
function P = MakePoint(x,y)
% P is a point with P.x and P.y
% assigned the values x and y.

P = struct('x',x,'y',y);
```

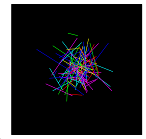
Then in a script or some other function…

```
a= 10;  b= rand;
Pt= MakePoint(a,b); % create a point struct
                    % according to definition
                    % in MakePoint function
```

Another function that has structure parameters

```
function DrawLine(P,Q,c)
% P and Q are points (structure).
% Draws a line segment connecting
% P and Q. Color is specified by c.

plot([P.x Q.x],[P.y Q.y],c)
```


Pick Up Sticks



```
s = 'rgbmcy';
for k=1:100
   P = MakePoint(randn,randn);
   Q = MakePoint(randn,randn);
   c = s(ceil(6*rand));
   DrawLine(P,Q,c)
end
```

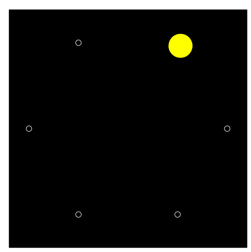
Generates two random points and connect them using one of six colors chosen randomly.

Structure Arrays

- An array whose components are structures
- All the structures must be the same (have the same fields) in the array
- Example: an array of points (point structures)

P	.5	.86	1.5	.91	.4	.28	2.5	1.8
	x	y	x	y	x	y	x	y
	P(1)		P(2)		P(3)		P(4)	

An Array of Points



.50	.86
x	y
P(1)	

`P(1) = MakePoint(.50,.86)`

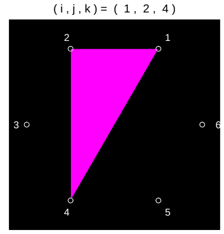
Function returning an array of points (point structures)

```
function P = CirclePoints(n)
%P is array of n point structs; the
%points are evenly spaced on unit circle

 theta = 2*pi/n;
 for k=1:n
    c = cos(theta*k);
    s = sin(theta*k);
    P(k) = MakePoint(c,s);
 end
```

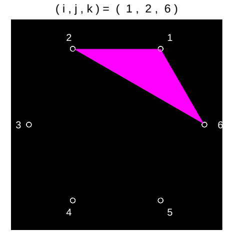

Example: all possible triangles

- Place n points uniformly around the unit circle.
- Draw all possible unique triangles obtained by connecting these points 3-at-a-time.

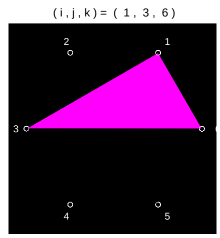
(i,j,k) = (1, 2, 4)

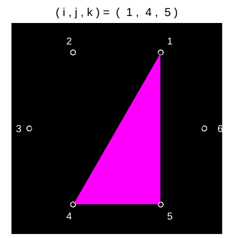


(i,j,k) = (1, 2, 6)



```
function DrawTriangle(U,V,W,c)
% Draw c-colored triangle;
% triangle vertices are points U,
% V, and W.

fill([U.x V.x W.x], ...
     [U.y V.y W.y], c)
```



The following triangles are the same: (1,3,6), (1,6,3), (3,1,6), (3,6,1), (6,1,3), (6,3,1)

Bad! i, j, and k should be different, and there should be no duplicates

```
% Given P, an array of point structures
for i=1:n
  for j=1:n
    for k=1:n
       DrawTriangle(P(i),P(j),P(k),'m')
       pause
       DrawTriangle(P(i),P(j),P(k),'k')
    end
  end
end
```


All possible (i,j,k) combinations but avoid duplicates.
Loop index values have this relationship i < j < k

i j k

i = 1	i = 2	i = 3	i = 4
1 2 3	2 3 4	3 4 5	4 5 6
1 2 4	2 3 5	3 4 6	
1 2 5	2 3 6	3 5 6	
1 2 6	2 4 5		
1 3 4	2 4 6		
1 3 5	2 5 6		
1 3 6			
1 4 5			
1 4 6			
1 5 6			

```
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      disp([i j k])
    end
  end
end
```


All possible (i,j,k) combinations but avoid duplicates.
Loop index values have this relationship i < j < k

```
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      disp([i j k])
    end
  end
end
```

```
for i=1:n
  for j=1:n
    for k=1:n
      if i<j && j<k
        disp([i j k])
      end
    end
  end
end
```

Both versions print all possible, unique combinations of (i,j,k), but the left fragment is far more efficient

All possible unique triangles

```
% Drawing on a black background
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      DrawTriangle( P(i),P(j),P(k),'m')
      DrawPoints(P)
      pause
      DrawTriangle(P(i),P(j),P(k),'k')
    end
  end
end
```

Still get the same result if all three loop indices end with n?

A: Yes   B: No

i j k

```
1 2 3      2 3 4      3 4 5      4 5 6
1 2 4      2 3 5      3 4 6      i = 4
1 2 5      2 3 6      3 5 6
1 2 6      2 4 5      i = 3
1 3 4      2 4 6
1 3 5      2 5 6
1 3 6      i = 2
1 4 5
1 4 6
1 5 6
i = 1
```

```
for i=1:n
  for j=i+1:n
    for k=j+1:n
      disp([i j k])
    end
  end
end
```

Lecture 20 35

Structures with array fields

Let's develop a structure that can be used to represent a colored disk. It has four fields:

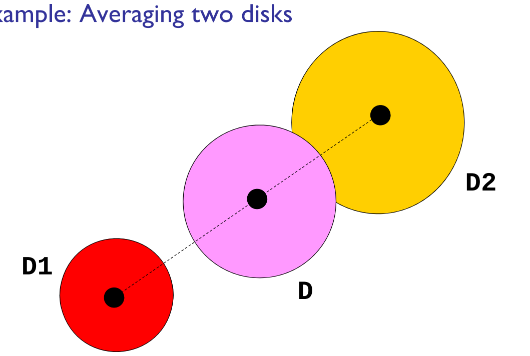
```
xc:  x-coordinate of center
yc:  y-coordinate of center
r:   radius
c:   rgb color vector
```

Examples:

```
D1 = struct('xc',1,'yc',2,'r',3,…
            'c',[1 0 1]);
D2 = struct('xc',4,'yc',0,'r',1,…
            'c',[.2 .5 .3]);
```

Lecture 20 37

Example: Averaging two disks



Lecture 20 40

Example: compute "average" of two disks

```
% D1 and D2 are disk structures.
% Average is:
r  = (D1.r  + D2.r) /2;
xc = (D1.xc + D2.xc)/2;
yc = (D1.yc + D2.yc)/2;
c  = (D1.c  + D2.c) /2;

% The average is also a disk
D = struct('xc',xc,'yc'yc,'r',r,'c',c)
```

Lecture 20 41

How do you assign to **g** the green-color component of disk **D**?

```
D= struct('xc',3.5, 'yc',2, ...
          'r',1.0, 'c',[.4 .1 .5])
```

A: `g = D.g;`

B: `g = D.c.g;`

C: `g = D.c.2;`

D: `g = D.c(2);`

E: *other*

Lecture 20 42

Different kinds of abstraction

- Packaging procedures (program instructions) into a function
  - A program is a set of functions executed in the specified order
  - Data is passed to (and from) each function
- Packaging data into a structure
  - Elevates thinking
  - Reduces the number of variables being passed to and from functions
- Packaging data, and the instructions that work on those data, into an object
  - A program is the interaction among objects
  - Object-oriented programming (OOP) focuses on the design of data-instructions groupings